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UNITED STATES
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BUREAU OF MINES
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INFORMATION CIRCULAR

MARKETING KYANITE AND ALLIED MINERALS

BY

NAN C. JENSEN

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MARKETING KYANITE AND ALLIED MINERALS[1/]

By Nan C. Jensen[2/]

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INTRODUCTION

Modern high-temperature metallurgical processes have created a demand for raw material for furnace parts and linings that not only will withstand high temperatures but will not react with the substance being melted in the furnace. Spark-plug insulators, laboratory ware, tanks for the glassmaking industry, and saggers and kiln furniture for the chinaware and pottery trades also must be made of materials that have high melting points. Among the minerals that can be employed for such refractory uses are those commonly known as the "sillimanite group" - kyanite, andalusite, sillimanite, and dumortierite - and the allied minerals topaz and pinite. Consideration of the occurrence, properties, qualities, uses, and sources of supply of these commodities and the markets for them constitute the subject of this paper.

General Features of Kyanite and Related Minerals

Kyanite, andalusite, and sillimanite are composed of three elements - aluminum, silicon, and oxygen - and are called aluminum silicates. They have

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7234."

2/ Nonmetal Economics Division, Bureau of Mines.

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the same chemical formula, Al_2SiO_5, but they differ in crystallization, specific gravity, and other physical properties. Dumortierite is somewhat similar in composition to andalusite, kyanite, and sillimanite but contains some boron oxide and water and conforms with the formula approximately $8Al_2O_3 \cdot 6SiO_2 \cdot B_2O_3 \cdot H_2O$. All four minerals upon heating to high temperatures lose their mineralogical identity and are broken down into mullite ($3Al_2O_3 \cdot 2SiO_2$) and a liquid (siliceous glass). The point at which decomposition takes place is directly influenced by the grain sizes and the time of heating. Changes in specific gravity and volume occur simultaneously with the conversion of the minerals to mullite. Topaz and pinite are also mullite-forming minerals but differ in chemical composition from the other minerals. Topaz is an aluminum fluosilicate, whereas pinite is a hydrous silicate of alumina and potash. Mullite is stable up to 1,810° C., the point at which it forms corundum and a liquid.

In the trade the terms "kyanite," "sillimanite," and "mullite" are often used loosely and interchangeably. "Sillimanite" appears to be the most common term in use. Early descriptions refer to the artificial product obtained by calcination of the aluminum silicates as "artificial sillimanite," and mullite was not recognized as a distinct mineral until the 1920's.

None of these minerals was mined to an appreciable extent until after World War I, and kyanite is virtually the only one of the group that has appeared on the market. Domestic production of andalusite and dumortierite has ranged from 400 to 2,000 tons a year but is consumed almost exclusively by the company that owns the two large mines. As far as is known, only two deposits of massive topaz and pinite are being worked. No sillimanite is known to have been produced commercially, and the only natural occurrence of mullite reported up to the present time is on the Island of Mull in the Western Isles of Scotland.

The products made from these minerals have good insulating power even at high temperatures, low thermal expansion, and resistance to heat and to the corrosive action of certain fluxing agencies and furnace gases.

KYANITE

Kyanite occurs in long-bladed or platy crystals, some of which may be 6 to 15 inches long, 2 inches wide, and 1/2 inch thick; in small tabular crystals ranging from almost microscopic size to 2 inches or more in length, 1/2 inch in width, and 1/16 inch in thickness; and in coarse-bladed, columnar, or fibrous masses. The crystals may be interlocking, parallel, or in a radial structure. They have a glassy to pearly luster and may be blue, white, colorless gray, green, brown, or black. The edges of the blades are usually lighter in color than the central parts. Small crystals distributed through large masses of rock are more common but not as easily recognizable as the long, bluish-whi

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flat-bladed crystals. The hardness of kyanite varies with direction; it is 4 to 5 (Mohs' scale) parallel to the long direction of the blades and 6 to 7 across the blades. (Quartz has a hardness of 7.) The specific gravity of kyanite is 3.56 to 3.67, whereas that of quartz is 2.65. Kyanite decomposes to mullite and a liquid (siliceous glass) upon heating, beginning at a temperature of about 1,350° C. (2,462° F.). The liquid formed from decomposition of the kyanite amounts to about 14 percent. The conversion to mullite is slow at lower temperatures, and in commercial practice the temperature attained should be as near 1,500° C. as practicable.3/

Decomposition is accompanied by a drop in specific gravity to 3.1 and an increase in volume. For most ceramic purposes, kyanite must be calcined above its dissociation point before incorporation into a body mix because of the increase in volume. However, in the production of high-alumina refractories the expansion of kyanite instead of being undesirable may be an advantage, as it may be used to neutralize the contraction of other refractory minerals that have high shrinkage, such as bauxite and diaspore. Pure kyanite contains 63 percent Al_2O_3 and 37 percent SiO_2. However, the commercial mineral contains varying amounts of impurities, the most common of which is quartz. A table appearing in a recent publication4/ gives the following analysis for kyanite: 57.4 percent Al_2O_3, 40.4 SiO_2, 0.9 TiO_2, 0.8 CaO, 0.5 Fe_2O_3, and a trace of MgO.

Kyanite occurs in many places in the belt of crystalline rocks that traverses the States along the Atlantic seaboard of the United States. The rocks of this belt were partly igneous and partly sedimentary but have been metamorphosed and now consist principally of schists and gneisses, which have been crumpled and folded. The kyanite occurs disseminated as small tabular crystals in the gneisses and schists. Where pegmatite dikes and quartz veins cut the kyanite schist, extremely large crystals of kyanite, many of which are 10 to 15 inches long, may be embedded in the dikes or veins. Near the surface the kyanite crystals are weathered out and in many places occur scattered over the surface of the ground. Lens-shaped or boulderlike masses of almost massive kyanite are distributed intermittently throughout the entire kyanite belt. The disseminated deposits containing the kyanite in relatively small crystals distributed through large masses of rock are the most common and are most important commercially.

One of the largest kyanite deposits in the United States is on Baker Mountain in Prince Edward County, south-central Virginia, about 7 miles southeast of Pamplin and 20 miles southwest of Farmville. It is worked by the

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3/ Searle, A. B., Refractory Materials - Their Manufacture and Uses: Charles Griffin & Co., Ltd., London, 1940, p. 386.

4/ Industrial Publications, Inc., Chemical Analysis of Some Ceramic Raw Materials: Ceramic Data Book, 14th ed., 1941-1942, p. 242.

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Kyanite Products Corporation (11 Broadway, New York City). The mine, which has been opened on top of the ridge, consists of a semicircular pit having a face about 200 feet long and walls of 35-foot maximum height. The kyanite occurs in quartzite beds enclosed in crystalline schists.5/ Impurities include rutile, hematite, pyrite, and quartz and are removed by grinding the quarried product to minus 35 mesh and processing it by flotation and magnetic separation. The resulting 93-percent kyanite concentrate may be washed in acid to give an even purer product containing only 0.32 percent Fe_2O_3. The corporation sells what it terms a "standard grade" kyanite concentrate containing a minimum of 90 percent kyanite and a maximum of 1.3 percent iron calculated as ferric oxide. (Personal communication from H. S. Doty, general manager, Kyanite Products Corporation.) The concentrate actually runs approximately 94 percent kyanite and about 1 percent iron. The iron is in nonmagnetic form and is not objectionable in most refractory work. A typical analysis of the "standard" kyanite is: 58.77 percent Al_2O_3, 37.70 SiO_2, 1.17 Fe_2O_3, 1.30 TiO_2, trace MgO, 0.59 K_2O and Na_2O, and 0.38 percent ignition loss. The regular operation produces material in minus 35-mesh grain size, of which about 55 to 60 percent will pass through 65 mesh and about 30 percent through 100 mesh. If a finer size is desired a charge is made for the grinding operation which amounts to $2 a net ton for grinding to 48 or 100 mesh, $5 for grinding to 200 mesh, and $15 for grinding to 325 mesh. There is an extra charge of $5 a net ton for calcining. Calcination is accomplished by firing, at approximately 1,450° C., 35-mesh raw grains in a rotary kiln having a capacity of about 2-1/2 tons an hour. At this temperature the kyanite is converted to mullite in 20 to 30 minutes. Research work sponsored by Kyanite Products Corporation is in progress at Virginia Polytechnic Institute on the use of binders and plasticisers to agglomerate the fine-grained Virginia kyanite into briquets that might subsequently be crushed or ground into products of large grain size comparable with those of large-grained Indian kyanite.

A disseminated deposit of considerable size occurs at the extreme north end of Black Mountain Range near Burnsville, N. C., in the Carolina gneiss. It is roughly cigar-shaped in horizontal section, about 2,000 feet long and 300 feet wide. It strikes north and dips west at about 77°. The rock consists of approximately 15 percent kyanite, 10 percent garnet, 30 percent mica, 5 percent miscellaneous minerals including pyrrhotite, pyrite, galena, and sphalerite, and the remainder quartz. The deposit was formerly operated by Mas-Celo Mines, Inc., under lease from Yancey Cyanite Co. The material was wet-ground in a ball mill. The kyanite and garnet were separated from the gangue minerals

5/ Hubbell, A. H., Mining Kyanite on Baker Mountain: Eng. and Min. Jour., vol. 142, No. 9, September 1941, pp. 40-42.
_____ Preparing Baker Mountain Kyanite for Market: Eng. and Min. Jour., vol. 142, No. 10, October 1941, pp. 53-55.

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by flotation, and the garnet was separated from the kyanite by high-intensity magnetic separators. The finished kyanite concentrate either was sacked directly or reground to 100 mesh or finer. The kyanite was calcined before shipment upon payment of an additional charge. In addition to refractory grades of kyanite, the corporation also produced an extra-low-iron kyanite concentrate for use in glass, whiteware, and special ceramic products. Mas-Celo Mines, Inc., ceased operations in June 1942, but the Yancey Cyanite Co. is now planning to operate the mine. (Personal communication from V. L. Mattson, manager, Yancey Cyanite Co.)

Near Clarkesville, Ga., the A. P. Green Fire Brick Co. (Mexico, Mo.) obtains kyanite from a deposit of surface crystals that have been weathered out of mica schists and from small gravel beds that contain concentrations of surface crystals. (Personal communication from Robert S. Green, A. P. Green Fire Brick Co.) The material taken from the small scattered deposits is brought to the mill, where dirt and much of the weathered mica is washed out in an 18-foot screw-type washer. A double-deck screen with 1-1/2-inch screen on top and a 12-mesh cloth on the bottom then separates the large gravel and the fine sand from a middle product that contains most of the kyanite. This product is put through a ring-type hammer mill with 1/4-inch screen plates, split on a 6-mesh screen, and run over two Pan-American jigs, one of which handles the coarse and the other the fine fractions. Mica and some sand are taken off and the kyanite is recovered through draws at the bottom of the ed. The company does not sell its kyanite on the open market but employs it in the manufacture of refractory products.

Occurrences of kyanite have been reported also in several Pacific Coast and Rocky Mountain States. A large quantity of rock containing kyanite and quartz in the proportion, roughly, of 1:2, with minor amounts of other minerals, including tourmaline, rutile, and hematite, has been mined from an extensive deposit at the base of the Chocolate Mountains near Ogilby, Imperial County, Calif., by the Vitrefrax Corporation (5050 Pacific Blvd., Los Angeles, Calif.). (Personal communication from R. W. Ellison, Director of Research, Vitrefrax Corporation.) During the grinding, done at the quarry, a slight concentration is made by means of a screening operation. The material is ground to pass a 40-mesh screen and shipped to the corporation's plant in Los Angeles, where it is employed in refractory products. The Western Nonmetallic Co. (5601 S. Boyle St., Los Angeles, Calif.) also produces kyanite near Ogilby, Calif.

Kyanite has been produced by the Southern Mining & Milling Co. at Clarkesville, Ga., and by B. J. Lachmund of Blacksburg, S. C., from the Henry Knob property in York County, S. C., but neither reported production in 1941.

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In India, large, well-rounded boulders of massive kyanite, which have been transported from their original undiscovered source, are found in the State of Kharsawan, about 100 miles west of Calcutta. They are hauled 10 miles in ox carts to the railroad, shipped to sea, and exported to the United States and England and formerly to Germany. The rock is chiefly kyanite but contains some sillimanite and a little andalusite in some specimens. It almost invariably contains some free corundum, which accounts for the unusually high alumina content of this material, and varying amounts of topaz. The material does not expand as much when calcined as the kyanite from the southern part of the United States, but it does expand much more than andalusite, dumortierite, or sillimanite.

The Chas. F. Taylor & Sons Co. of Cincinnati, Ohio, imports Indian kyanite for use in its P. B. Sillimanite refractories. At the plant in Cincinnati the boulders are piled into a round, down-draft, brick kiln and calcined to break them up so that the material can easily be crushed and ground to desired sizes for manufacturing processes, and the product will be free from any conversion volume changes in later burns. Other importers of Indian kyanite include Golwynne Magnesite & Magnesia Corporation, 1944 Graybar Bldg., New York City, and B. G. McNabb, 138 Glen Park Ave., Gary, Ind.

Shipments of domestic kyanite in 1941 totaled 8,335 short tons valued at $175,581 f.o.b. mines, compared with 4,241 tons valued at $93,716 in 1940 and 2,950 tons valued at $69,000 in 1939, as reported in the annual volumes of Bureau of Mines Minerals Yearbook. Domestic kyanite in 1941 sold at prices ranging from $3 a short ton at the mine for crude to around $78 a ton f.o.b. plant for extra high-grade material that had been calcined and ground to minus-325 mesh. The average price of all domestic kyanite sales in 1941, as reported to the Bureau of Mines by producers, was $21.07 a short ton, f.o.b. mines. The December 3, 1942, issue of Engineering and Mining Journal Metal and Mineral Markets contained the following quotation: "Kyanite - per ton, f.o.b. North Carolina and Georgia, $22 to $32." Extra-low-iron grades carry a substantial premium. The following base prices on 35-mesh kyanite are quoted by the Kyanite Products Corporation: Per ton, f.o.b. Cullen or Pamplin, Va., in carload lots, bulk, $19; in carload lots, 100-lb. paper bags, $21.50; and in less than carload lots, 100-lb. paper bags, $22.50. Finer-ground kyanite is sold at these prices plus the extra charges for grinding mentioned on page 4 of this circular.

Imports of kyanite into the United States, all from British India, as reported by the Department of Commerce for the first nine months of 1941, totaled 6,211 short tons valued at $81,356 (foreign market value), compared with 7,658 tons valued at $92,159 in the full year of 1940. Because of war conditions, import statistics for 1941 are available for publication for the first

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9 months only. Under normal conditions Indian kyanite is worth, roughly, $20 a short ton delivered in the United States. However, because of war conditions shipping rates were increased in 1941, and the price rose to over $30.

Kyanite is used in the manufacture of refractories, in various ceramic products, and as a source of alumina in a low-alkali type of glass. Bladed crystals of kyanite have been cut into small stepped gem stones, blue to grayish blue and not always transparent.

According to Heuer,[6] kyanite refractories possess ability to bear high loads at high temperatures and have volume stability and resistance to thermal shock. Because of these properties, kyanite refractories are important even though they represent only a small percentage of the total tonnage of refractories used in the United States. They are made in prefabricated and burned shapes such as brick, tile, and block, and into plastics, cements, ramming mixes, and mortars. About 50 percent of the kyanite refractories produced in the United States are used by the metallurgical industries. Kyanite, fused alumina, or similar refractories are required in furnaces in which are melted brasses and bronzes that contain more than 75 percent copper, copper-nickel alloys, and other high-melting-point copper alloys. This is about 25 percent of the total brass melted. Alumina and magnesia-alumina refractories have the same life as the kyanite refractories but are more difficult to install, whereas fire-clay refractories are said to have only one-tenth the life of kyanite in furnaces melting high-melting-point alloys. Kyanite and high-alumina refractories also are used in indirect-arc furnaces in which some steel and ferrous alloys are melted, for which use the high-alumina refractories are equally serviceable when temperatures are not too high. However, above 1,649° C. (3,000° F.) they are said to have only half the life of kyanite. Kyanite bricks are employed to construct the roofs in many small direct-arc electric furnaces and to a lesser extent in larger furnaces for ferrous melting. The initial cost of these roofs is higher but they last longer than those made of silica bricks. Appreciable amounts of kyanite refractories are used in electric-furnace door jambs and arches, burner blocks, and burner tunnels for heat-treating furnaces. Kyanite also is employed in burner blocks in the superstructures of glass tanks; plungers, rings, and tubes for feeding molten glass to forming machines; saggers and other kiln furniture for the chinaware and pottery trade; and porcelain.

ANDALUSITE

Andalusite occurs in coarse, nearly square prismatic forms; in fibrous, imperfectly columnar, radiated, and granular masses; and in rounded pebbles.

6/ Heuer, R. B., How and Where Kyanite Refractories are Used: Brick & Clay Record, vol. 100, No. 3, March 1942, pp. 50-51.

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The coarsely granular masses are the chief source of the economic product. Andalusite has an uneven fracture, a hardness of 7.5, and a specific gravity of 3.16 to 3.23; it is infusible, insoluble in acids, and gray, green, red, brown, yellow, or blue with a glassy to dull luster. It decomposes to mullite and a liquid (siliceous glass) beginning at a temperature of about 1,390° C. (2,534° F.). Some authorities give the decomposition temperature as 1,475° C. and others as 1,500° to 1,700° C.7/ Decomposition is accompanied by a slight drop in specific gravity to 3.1, but no appreciable change in volume occurs. Pure andalusite is composed of 63 percent Al_2O_3 and 37 percent SiO_2. Chiastolite is a variety of andalusite containing carbonaceous impurities arranged axially to form black crosses.

Andalusite occurs in schists, slates, quartzite, and other metamorphic rocks. Pegmatites and associated intrusives yield some andalusite as well as kyanite but have not been commercially productive. The occurrence of andalusite is largely limited to areas of metamorphic activity or to transported material derived from metamorphic rocks.

The world's leading andalusite mine is operated near Mocalno, Mono County, Calif., on the west slope of White Mountain, by Champion Sillimanite, Inc. (P. O. Box 117, Laws, Inyo County, Calif.). The andalusite occurs in a cliff at an altitude of 10,000 feet. Although it occurs virtually throughout the great mass of quartz composing the cliff, it is found in commercial concentrations only in certain spots. The rock in these areas (which are irregular in shape and distribution and extend over a considerable distance) generally averages at least 75 to 85 percent andalusite. Other minerals contained include corundum, lazurite, pyrophyllite, muscovite, rutile, pyrite, barite, and lazulite. A typical chemical analysis of the rock shows 56.89 percent Al_2O_3, 33.78 SiO_2, 0.37 H_2O, 3.67 ignition loss, and 5.29 percent other constituents. The various minerals associated with the andalusite in small quantities are not objectionable when the andalusite is employed in spark-plug insulators, but some are objectionable when employed in refractories. Therefore, tests are run at the mine at frequent intervals, and the rock is mined and blended accordingly. The rock is mined from large chambers and stopes, which are connected by a series of drifts. To maintain a stock pile of constant composition, the proportion of rock mined at each of the workings is determined daily on the basis of the grade of rock produced. The rock is broken down by drilling and blasting with 40-percent nitroglycerine dynamite, then cobbed and sacked, and conveyed by pack mules down a steep trail 4-1/2 miles to a point where it can be transferred to a truck and taken to a storage platform along a narrow-gage railroad 3

7/ Searle, A. B., Work cited in footnote 3, p. 149.

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miles from the foot of the trail. When the rock is withdrawn from the stock piles it is removed in layers at right angles to the original piling, a method that tends to maintain a uniform chemical composition.

The andalusite from White Mountain shipped to the plant of the Champion Spark Plug Co. at Detroit, Mich., is usually mixed with a small percentage of dumortierite before it is crushed and treated. The spark-plug insulators made from the andalusite-dumortierite mixture are burned in a kiln, and because of the transformation of andalusite and dumortierite at the furnace temperatures the finished products consist of a mixture of mullite and siliceous glass. The andalusite and dumortierite can be used without previous calcination because they undergo no appreciable volume change when converted to mullite. The andalusite from White Mountain also is employed by the Coors Porcelain Co. of Golden, Colo., in the manufacture of laboratory porcelain and thermocouple protection tubes.

Andalusite occurs near Hawthorne, Mineral County, Nev., where it is associated with corundum and diaspore in a vertical, veinlike deposit 2 to 4 feet thick and approximately 3,000 feet long. The mine is owned by B. H. Donnelley and was formerly operated by the Tillotson Clay Products Co. (Los Angeles, Calif.).

Andalusite has been reported in several localities on Oak Hill, west and southwest of Littleton, Mass.,[8/] where it is distributed sparingly but with comparative uniformity throughout a large mass of fine-grained schist. Concentrates can be obtained economically only by mechanically treating fairly large quantities of material.

Occurrences of andalusite in small amounts also have been reported in the Black Hills of South Dakota, in India, and in several other places.

Although little, if any, andalusite enters the open market, a nominal value of $10 to $15 a ton at the mine has been placed on the White Mountain andalusite. The andalusite is employed in the manufacture of spark-plug insulators, other high-tension electric insulators, laboratory ware, and thermocouple protection tubes. Andalusite ramming mixes and patching mixes have been on the market for some time and have found a favorable use in electric-furnace repair work. (Personal communication from H. F. Royal, Ceramic Division, Champion Spark Plug Co.) Products made from andalusite resist sudden changes of temperature and have high electrical resistivity at high

8/ Commonwealth of Mass. Dept. of Pub. Works and U. S. Geol. Survey, Occurrence of Andalusite in Massachusetts: Coop. Geol. Project Inf. Circ., February 1942, 8 pp.

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temperatures and tensile strength three to five times that of products made of ordinary electrical porcelain.9/ Andalusite employed in the manufacture of pyrometer tubes is said not only to retain its shape at high temperatures but to lengthen the life of the rare-metal thermocouple by excluding injurious gases such as carbon monoxide.

Transparent varieties of andalusite, usually green, brown, and yellow, are frequently used as gem stones and are cut in the step fashion.

SILLIMANITE

Sillimanite occurs in long, slender, prismatic crystals nearly square in cross section or in radiating fibrous or columnar masses. It is gray, brown, yellow, or green, and has a glassy or silky luster, a hardness of 6 to 7, a specific gravity of 3.23, and an uneven fracture. Sillimanite decomposes slowly to mullite and a liquid (siliceous glass) at about 1,545° C. (2,813° F). At 1,700° C (3,092° F.) the dissociation is rapid.10/ Decomposition is accompanied by a slight drop in specific gravity to 3.1 with a small and fairly uniform expansion in volume. Pure sillimanite is composed of 63 percent Al_2O_3 and 37 percent SiO_2.

This mineral occurs in gneisses, schists, slates, and other metamorphic rocks but is less common than kyanite and andalusite. Many scattered occurrences have been reported. However, commercial concentrations have been found only in remote regions of India. The sillimanite in the deposits of the Khasi Hills, Assam, India, is white, gray, or brown and occurs chiefly in massive form, although some of it is the fibrous variety. Sillimanite concentrations also occur near Pipra, Rewa, India, but the deposits cannot be mined profitably because of transportation difficulties and high freight charges.

Several small outcrops have been opened in the United States, chiefly in South Dakota. The sillimanite of the Black Hills occurs in fibrous, crystalline aggregates in an area of metamorphic rock and is associated with quartz. It is generally white or ash gray, less commonly dark gray, and commonly resembles masses of badly splintered wood.

No mining of sillimanite on a commercial scale has been reported. Most of the sillimanite products on the market have been made from kyanite, andalusite, or dumortierite.

9/ Jeffery, J. A., and Woodhouse, C. D., A Note on a Deposit of Andalusite in Mono County, Calif. - Its Occurrence and Technical Importance: Calif. Bureau of Mines, Mining in California, vol. 27, No. 3, July 1931, pp. 459-464.

10/ Searle, A. B., Work cited in footnote 3, p. 148.

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DUMORTIERITE

Dumortierite occurs in fan-shaped, radiating masses and in fibrous, acicular, or prismatic crystals, in spherulitic aggregates, or as inclusions in other minerals. The crystals are commonly vertically striated on the prism faces. The mineral shows a range of colors from intense blue to deep pinkish lilac, has a glassy to dull luster, a specific gravity of 3.26 to 3.36, and a hardness of 7. It is infusible before the blowpipe, becomes permanently gray or white when heated for a few seconds above 800° C. (1,472° F.), and is resistant to weathering. Dumortierite decomposes to mullite and a liquid (siliceous glass) upon heating, beginning at about 1,250° C. (2,174° F.), its boron content being volatilized. The liquid formed from the decomposition of the dumortierite amounts to about 4 percent. Decomposition is accompanied by a slight drop in specific gravity to 3.1 with a very small expansion in volume. An analysis of Nevada dumortierite shows a content of 55.01 percent Al_2O_3, 37.05 SiO_2, 4.65 B_2O_3, and 3.29 percent oxides of various metals.11/

Dumortierite occurs associated with granites, pegmatite dikes, high-temperature quartz veins, and contact metamorphic deposits. It usually occurs in minor amounts as fibrous, acicular, and fan-shaped inclusions in other minerals such as quartz, muscovite, and feldspar, but in places it occurs in large masses. Dumortierite is classed as a rare mineral, but it has a world-wide distribution. Occurrences have been reported in Arizona, California, Colorado, Nevada, New Mexico, New York, Washington, and several foreign countries. However, the Humboldt Queen deposit, 6 miles east of Oreana, Pershing County, Nev., owned by Champion Sillimanite, Inc., is the only known commercial occurrence in the world. The deposit is near the head of a small canyon locally known as Humboldt Queen Canyon. Dumortierite occurs here in lenses, veins, and stringers in sericite schist; as fibrous inclusions in the schist; and as residual surface boulders in the alluvium above the schist; also in veins and stringers cutting quartz, or as fibrous inclusions in the quartz. The greater part of the dumortierite produced has come from boulders and lenses.

The dumortierite taken both from surface workings and from a lower drift, where it cuts the mineralized zone, is sorted and shipped from the mine near Oreana, Nev., to the plant of the Champion Spark Plug Co. at Detroit, Mich., where it is mixed with andalusite and employed in the manufacture of spark-plug insulators. Dumortierite expands only slightly upon conversion to mullite and therefore is employed without previous calcination. The function of dumortierite in spark-plug insulators and electrical porcelain is to increase

11/ Grawe, O. R., The Mineralogy of Dumortierite: The Mineral Dumortierite: Univ. of Nevada Bull., vol. 22, No. 2, March 1928, p. 20.

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the electrical resistivity and widen the burning range rather than to overcome any tendency of andalusite to sag, as stated in some publications. Dumortierite is valuable for use in such places as spouts for glass tanks, because it resists the eroding effect of the molten glass remarkably well. The mineral forms a good basis for refractory material because of its high alumina content. A nominal value of $10 to $15 a ton at the mine has been placed on dumortierite.

MULLITE

When well developed, mullite forms in long, prismatic crystals almost square in cross section. It is colorless or gray and has a hardness of 6 to 7 and a specific gravity of 3.156. Theoretically, mullite contains 71.8 percent Al_2O_3 and 28.2 percent SiO_2, but analysis of a specimen from the Island of Mull showed it to contain 69.63 percent Al_2O_3, 29.04 percent SiO_2, and 1.33 percent oxides of various metals. Mullite is a desirable constituent of refractories, as it shows little or no softening below its melting point of 1,810° C. (3,290° F.), and its needlelike structure contributes to high mechanical strength. Mullite is heat-resistant, a good insulator even at high temperatures, and resistant to shock; also, it imparts great tensile strength, high dielectric properties, and low thermal expansion to material containing it. Mullite forms corundum and a liquid at 1,810° C.

Mullite was made and recognized in the laboratory before it was discovered in nature, because it occurs in long, needlelike crystals in nearly all fired ceramic products. The only natural occurrence of mullite reported to the present time is in fused argillaceous sediments found as inclusions in igneous intrusions on the Island of Mull in the Western Isles of Scotland. The aluminum silicate, $3Al_2O_3 \cdot 2SiO_2$, into which kyanite, andalusite, sillimanite, and dumortierite are converted above their decomposition points, was named "mullite" because of its agreement with the rare mineral of that name. Mullite also is made synthetically by mixing the correct proportions of clay and alumina and heating to 1,400° C. (2,552° F.). A pure kaolin or china clay and pure alumina may be used, but for most purposes a fire clay and white bauxite are used.12/ Mullite is made also by mixing silica and alumina in suitable proportions and heating above 1,100° C. (2,012° F.).13/

Mullite is employed in spark-plug insulators, glass-tank blocks for the glassmaking industry, saggers, furnace-lining mufflers, and parts of furnaces subjected to high temperatures.

12/ Searle, A. B., Work cited in footnote 3.

13/ Tyler, Paul M., and Heuer, R. P., Refractories: Am. Inst. Min. and Met. Eng., Industrial Minerals and Rocks, New York, 1937, p. 619.

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The following base prices on 35-mesh mullite (calcined kyanite) are quoted by the Kyanite Products Corporation: Per ton, f.o.b. Cullen or Pamplin, Va., in carload lots, 100 lb. paper bags, $26.50; and in less than carload lots, 100 lb. paper bags, $27.50. Finer-ground material is sold at these prices plus the extra charges for grinding mentioned on page 4 of this circular.

Before cessation of its operations in June 1942, Mas-Celo Mines, Inc. (Burnsville, N. C.), quoted $78 a short ton for an extra-low-iron grade of mullite ground to 325 mesh, made by calcining in rotary kilns a 98-percent kyanite concentrate having an iron content of less than 0.1 percent Fe_2O_3. This product was sold for use in the manufacture of refractories, particularly glasshouse refractories and refractory cements.

TOPAZ

Topaz occurs in prismatic crystals commonly vertically striated and having usually only one end terminated with pyramidal faces; also in granular or compact masses and as water-worn fragments. Topaz may be colorless, wine-yellow, brown, gray, violet, red, or blue. It has a vitreous luster, a specific gravity of 3.4 to 3.6, a hardness of 8 on Mohs' scale, a conchoidal to uneven fracture, and a perfect basal cleavage. It is infusible and only slightly attacked by sulfuric acid. Topaz is converted almost entirely to mullite upon heating to 1,500° C. (2,732° F.). Its thermal expansion upon conversion is reported to be small. Topaz has the chemical formula $Al_2(F,OH)_2SiO_4$. In addition to aluminum, silicon, and oxygen, it contains varying percentages of fluorine and hydroxyl.

Topaz occurs in crevices, cavities, and pegmatite dikes in highly acid igneous rocks such as granite and rhyolite, in gneisses and schists, and frequently in stream gravels. Clear, transparent crystals are classed as gem stones. However, in recent years a massive topaz rock occurring near Jefferson, S. C., has gained recognition as a refractory. It is very fine-grained, with a texture similar to that of flint or chert, and differs from the gem topaz in that it has a waxy luster and a hardness of about 7 - the same as that of quartz. Some specimens show the pattern of a breccia, and others are marked with wavy lines or bands representing structures of previously existing rocks that the topaz has replaced. It breaks with a conchoidal fracture and separates along joints into rather small, smooth-faced blocks, which are gray, mottled, or streaked with white, cloudlike bands in a dull, gray mass.

As far as known, the only deposit of massive topaz of considerable size is at the Brewer mine, 1-1/2 miles northwest of Jefferson, Chesterfield County, S. C., where a rock composed almost entirely of very fine-grained topaz forms

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a part of the gold-bearing lode. The deposit is owned by the United Feldspar & Minerals Corporation, 10 E. 40th St., New York City. According to Fries:[14]

> The topaz forms irregular replacement bodies, ranging in thickness from a fraction of an inch to about 10 feet, which appear to be grouped roughly along lines that trend northeast and northwest, the longest group observed being about 100 feet long. The topaz also forms narrow veinlets that cut across the foliation in the schist, and thin lenses in the planes of schistosity; and grains of topaz are disseminated in the schist at some places.****. The district contains probable reserves amounting to about 106,000 tons of rock averaging at least 15 percent topaz; this material contains roughly 16,000 tons of topaz, most of which probably can be recovered. In addition, there are possible reserves of about 194,800 tons of topaz-bearing rock of the same grade, which would contain roughly 29,000 tons of topaz. Further exploration may reveal other zones of sufficient size to mine.

The country rock is a quartz-sericite schist, and in general the massive topaz resembles the undecomposed quartz rock of the lode but can be distinguished from the quartz by its greater weight.[15] Analysis of the massive topaz is as follows:

SiO_2	33.00
Al_2O_3	56.76
Fe_2O_3	trace
H_2O-	0.04
H_2O+	2.67
F	13.23
	105.70
Minus O = F	5.57
	100.13

F^- and OH^- may replace each other to some extent, and some of the Al_2O_3 reported as 56.76 percent represents AlF_3. The Brewer topaz possesses the lowest fluorine and highest water content of any topaz known. Most of the fluorine and water, considerable silica, and some iron oxide are eliminated by heating at 850° to 900° C. The color of the topaz when fired is buff to light brown up to 850° C., but at 900° C. and higher it is pure white. At 1,500° C.

14/ Fries, Carl Jr., Topaz Deposits Near the Brewer Mine, Chesterfield County, S. C.: Geol. Survey Bull. 936-C, 1942, pp. 59-60.

15/ Pardee, J. T., Glass, J. J., and Stevens, R. E., Massive Low-Fluorine Topaz from the Brewer Mine, S. C.: Am. Mineralogist, vol. 22, No. 10, October 1937, pp. 1058-1064.

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the material, which has been converted almost entirely to mullite, carries 69.21 percent Al_2O_3, 29.85 percent SiO_2, and 0.94 percent Fe_2O_3 and F_2.

The United Feldspar & Minerals Corporation began mining topaz in 1941 largely for exploratory and experimental purposes, and by August 1941 had shipped to prospective consumers about 200 tons of topaz mined from bedrock and 500 tons of topaz float. The value of topaz concentrates will probably be at least $15 a ton at the mine and possibly as high as $30, depending on the size and purity of the material, and the value of rock containing 15 percent topaz probably will be $2.25 to $4.50 a ton.

Possibilities for the mineral include its employment in the manufacture of mullite refractories and spark-plug insulators. Conclusions drawn by Stuckey and Amero[16] from an investigation of the physical properties of the massive material indicate that (1) topaz replacements improve the properties of a fire-clay refractory body; (2) although high topaz replacements reduce spalling resistance, precalcination might decrease this spalling tendency; and (3) topaz fires to a good white color, it is converted to mullite at a relatively low temperature, and it has a low thermal expansion, which suggests that it should serve the same purpose as andalusite and dumortierite in electrical porcelain, particularly in spark-plug bodies.

PINITE

Pinite is another mineral that is convertible to mullite by firing and has found employment as a refractory material in recent years. It has a hardness of 3 (Mohs' scale), a specific gravity of 2.85, and is dull gray, green, or brown. Certain varieties resemble sericite in appearance, whereas massive pinite resembles steatite or pyrophyllite. Pinite is essentially a hydrous silicate of alumina and potash and has virtually the same composition as muscovite. Several secondary minerals derived from the alteration of feldspar, nepheline, and certain other silicates are classed as pinite.

A large deposit of pinite is being mined on the east side of the Humboldt Range near Rochester, Nev., by the Clay Corporation of California (1769 Russ Bldg., San Francisco, Calif.). The main pinite body is gray, shading into nearly white, and is easily scratched with a knife or pick. Silicified tuff overlies and underlies the pinite. The deposit is near the ridge separating the south fork of the American Canyon from the main valley and is 39 miles from Lovelock, Pershing County, Nev., and 25 miles from Oreana, Nev., the nearest railroad point. The output is shipped to the Stockton Firebrick Co. at Pittsburg, Calif., for manufacture into firebrick.[17]

16/ Stuckey, J. L., and Amero, J. J., Physical Properties of Massive Topaz: Jour. Am. Ceram. Soc., vol. 24, No. 3, March 1941, pp. 89-92.

17/ Tyler, Paul M., Pinite - A New Refractory: Bureau of Mines Mineral Trade Notes, vol. 9, No. 5, November 20, 1939, pp. 18-19.
Minor Nonmetals: Bureau of Mines Minerals Yearbook 1940, Review of 1939, p. 1479.

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According to Page, Raine, and Sullivan, of the Stockton Firebrick Co.,[18] the important properties of pinite are refractoriness, ease of raw grinding, snow-white color after firing, conversion to mullite at relatively low temperatures (1,125° C.), low and reversible thermal expansion, absence of free silica, extreme hardness and resistance to abrasion of the fired product, low firing shrinkage, high density after firing, and resistance to molten-enamel slags. Pinite refractories have been employed principally as linings in the cooler zones of rotary cement, lime, and magnesite kilns, in coolers for material discharged from rotary kilns, and in rotary enamel-smelting furnaces, and are reported to last longer than linings made of other materials.

BUYERS

The following list of possible buyers includes firms and individuals that have indicated to the Bureau of Mines that they are potential buyers, and additional firms taken at random from trade directories such as Thomas' Register of American Manufacturers and MacRae's Blue Book, which are available in most public libraries and local chambers of commerce.

Possible Buyers of Kyanite and Allied Minerals

California:
Vitrefrax Corporation, 5050 Pacific Blvd., Los Angeles.

Connecticut:
Mullite Refractories Co., 1939 Fyfe St., Shelton.

Illinois:
Chicago Firebrick Co., 1467 N. Elston Ave., Chicago.
F. E. Schundler & Co., 606 Railroad St., Joliet.

Maryland:
Locke Insulator Corporation, P. O. Box 57, Baltimore.

Michigan:
Champion Spark Plug Co., Ceramics Division, 8525 Butler Ave., Detroit.
General Motors Corporation, A C Spark Plug Division, Flint.

18/ Page, G. A., Raine, F. F., and Sullivan, V. R., Development and Preliminary Studies of Pinite: Jour. Am. Ceram. Soc., vol. 23, No. 3, March 1940, pp. 71-77.

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Missouri:

A. P. Green Fire Brick Co., 1108 Breckenridge St., Mexico.
Laclede-Christy Clay Products Co., 1706 Ambassador Bldg., St. Louis.
Mexico Refractories Corporation, Mexico.
Walsh Refractories Corporation, 4428 N. 1st St., St. Louis.

New Jersey:

Carborundum Co., Perth Amboy.
Seaboard Refractories Co., Perth Amboy.

New York:

Babcock & Wilcox Co., 85 Liberty St., New York.
Corning Glass Works, 1940 Crystal St., Corning.
Electro Refractories & Alloys Corporation, 6620 Andrews Bldg., Buffalo.
Golwynne Magnesite & Magnesia Corporation, 1944 Graybar Bldg., New York.
Johns-Manville Sales Corporation, 22 E. 40th St., New York.
A. D. Mackay, 198 Broadway, New York.
Quigley Co., Inc., 58 W. 45th St., New York.
R. T. Vanderbilt Co., 230 Park Ave., New York.

Ohio:

Colonial Insulator Co., Firestone Park, Akron.
Electrical Refractories Co., 1936 Clark St., East Palestine.
North American Refractories Co., 613 Euclid Ave., Cleveland.
Chas. F. Taylor & Sons Co., 715 Burns St., Cincinnati.

Pennsylvania:

Findlay Clay Products Co., Washington.
General Refractories Co., Broad and Chestnut Sts., Philadelphia.
Harbison-Walker Refractories Co., Farmers Bank Bldg., Pittsburgh.
E. J. Lavino & Co., 1528 Walnut St., Philadelphia.
Pittsburgh Plate Glass Co., 2222 Grant Bldg., Pittsburgh.

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